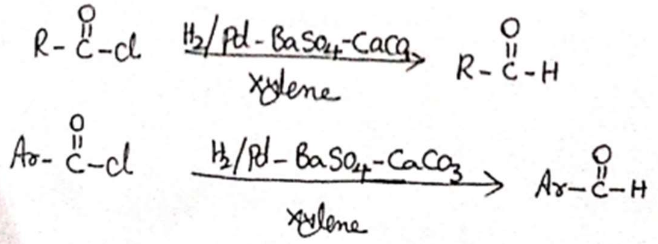
CARBONYL COMPOUNDS

Methods of Preparation

1. Preparation from Acid chlorides

Rosenmunds Reduction:

Acid chlorides on partial reduction give aldehydes. This reduction takes place in presence of Lindlar's Catalyst ($Pd-BaSO_4-CaCO_3$)



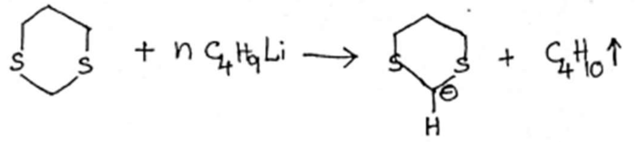
$$R-\overset{O}{\overset{\|}{C}}-Cl \xrightarrow[\text{xylene}]{H_2/Pd-BaSO_4-CaCO_3} R-\overset{O}{\overset{\|}{C}}-H$$

$$Ar-\overset{O}{\overset{\|}{C}}-Cl \xrightarrow[\text{xylene}]{H_2/Pd-BaSO_4-CaCO_3} Ar-\overset{O}{\overset{\|}{C}}-H$$

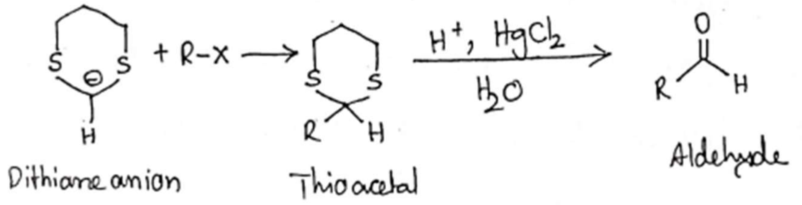
2. Preparation from 1,3-dithiane

a) Preparation of Aldehydes

1,3-dithianes reacts with strong bases such as n-butyllithium undergo deprotonation and forms Carbanion.

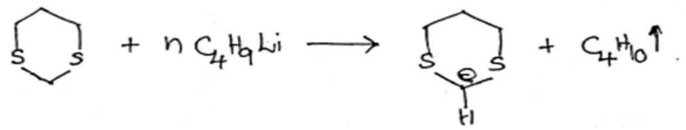


Alkylation of dithiane anion by 1° alkyl halide gives thioacetal, which can be hydrolysed in acidic solution of mercuric chloride

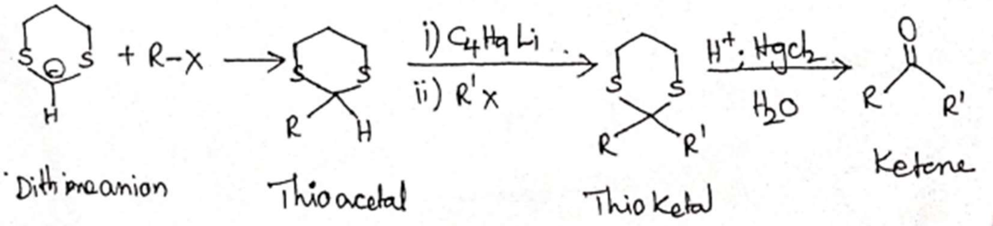


b) Preparation of Ketones

1,3 dithianes reacts with strong bases such as n-Butyl lithium undergo deprotonation and forms Carbanion.

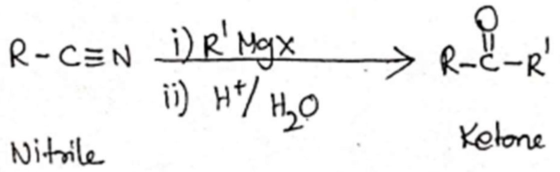


Alkylation of dithiane anion by 1° Alkyl halide gives thio acetal, Further alkylation of thioacetal followed by hydrolysis gives Ketones as final product



3. Preparation from nitriles or Cyanides

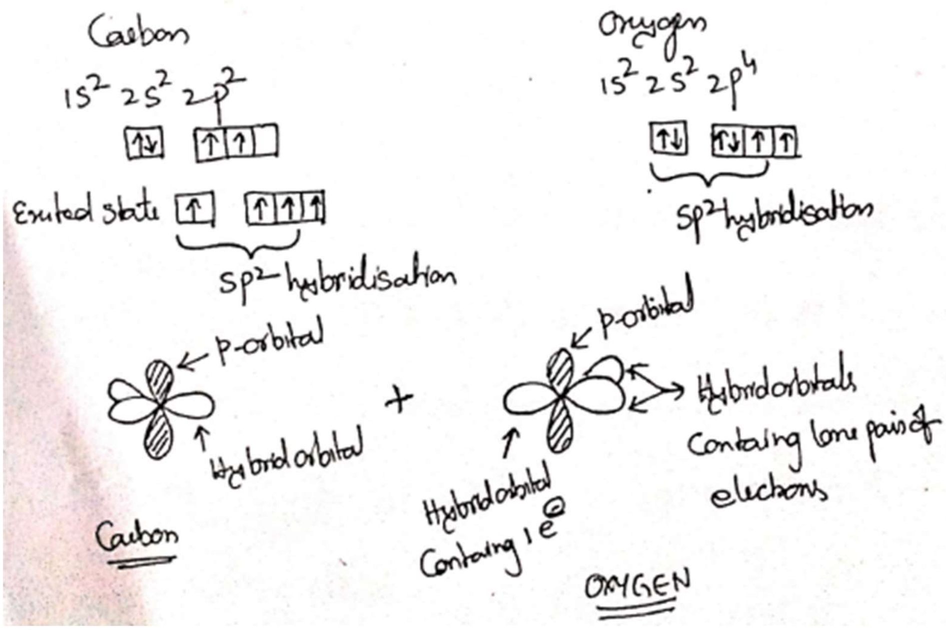
Nitriles on reaction with Grignard reagent and Acidic hydrolysis Produces Ketone as product.

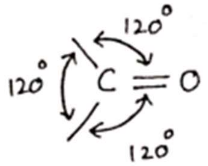


$$R-C\equiv N \xrightarrow[\text{ii) } H^+/H_2O]{\text{i) } R'MgX} R-\overset{O}{\overset{\|}{C}}-R'$$

Structure of carbonyl group

Carbonyl group is composed of one σ and one π bond $(>C=O)$ In Carbonyl group, the hybridisation of Carbon is sp^2. out of the three sp^2 hybridised orbitals one sp^2 hybridised orbitals overlaps with p-orbital of oxygen to form C–O σ bond. The remaining two sp^2 hybridised orbitals of Carbon forms σ bonds with s-orbital of hydrogen (or) sp^3 orbital of Alkyl group. The Three σ-bonds of the Carbonyl Carbon utilise sp^2 orbitals they lie in one plane at 120° apart. C–O π bond is formed by the sideways overlap of p orbitals of Carbon and oxygen.





Due to electronegativity of oxygen atom the π electron cloud is attracted towards oxygen. So Oxygen attains a partial -ve charge and Carbon attains Partial +ve charge. This polar nature of Carbonyl group Causes intermolecular attractions in aldehydes and Ketones. and hence responsible for higher boiling Points.

Reactivity of carbonyl group

A) Carbonyl group as a site for nucleophilic addition

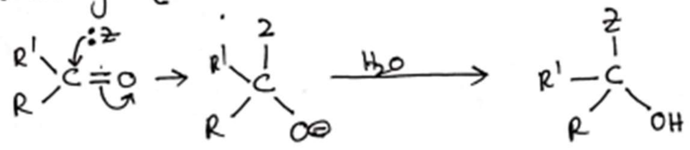
The π e⁻s of C=O are pulled strongly towards oxygen which makes Carbonyl oxygen electron rich and Carbonyl Carbon electron deficient.

The +ve charge on Carbon atom means that it is easily attacked by a nucleophile.

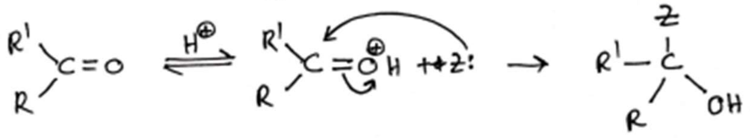
The -ve charge on oxygen atom means that nucleophilic addition is susceptible to acid catalysts.

Thus the nucleophilic addition to the C=O occurs in either of two ways

1. when the reagent is strong nucleophile, addition takes place in the following ways



2. when reaction is catalysed by acid then Nucleophilic addition takes place in the following ways

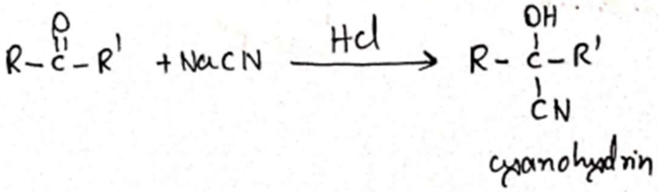


Chemical reactions

A) Nucleophilic addition reactions

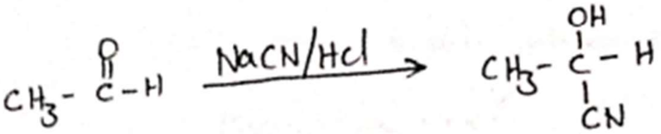
a) Addition with Hydrogen Cyanide (HCN)

Because HCN is toxic gas, the bestways to carry out this reaction, to generate gas HCN during the reaction by adding HCl to a mixture of Carbonyl Compound and excess of NaCN



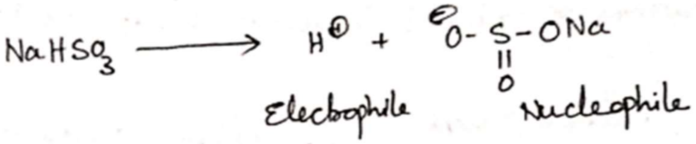
$$R-\overset{O}{\overset{\|}{C}}-R' + NaCN \xrightarrow{HCl} R-\underset{CN}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-R'$$

cyanohydrin



$$CH_3-\overset{O}{\overset{\|}{C}}-H \xrightarrow{NaCN/HCl} CH_3-\underset{CN}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-H$$

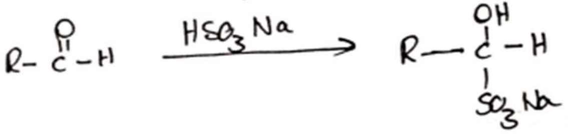
b) Addition with NaHSO₃



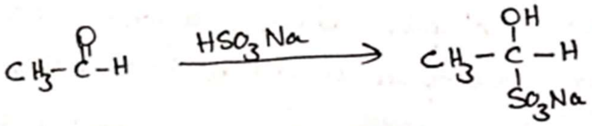
$$NaHSO_3 \longrightarrow H^{\oplus} + {}^{\ominus}O-\underset{O}{\underset{\|}{S}}-ONa$$

Electrophile Nucleophile

i) All types of aldehydes gives addition reaction with this reagent

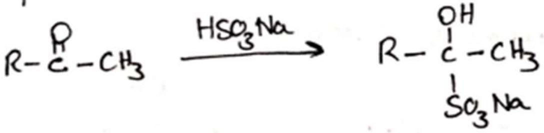


$$R-\overset{O}{\overset{\|}{C}}-H \xrightarrow{HSO_3Na} R-\underset{SO_3Na}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-H$$

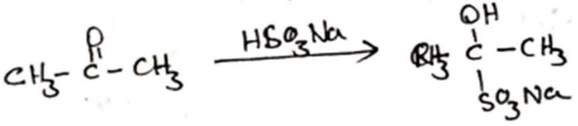


$$CH_3-\overset{O}{\overset{\|}{C}}-H \xrightarrow{HSO_3Na} CH_3-\underset{SO_3Na}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-H$$

ii) only aliphatic methyl ketones gives addition reaction



$$R-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow{HSO_3Na} R-\underset{SO_3Na}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-CH_3$$



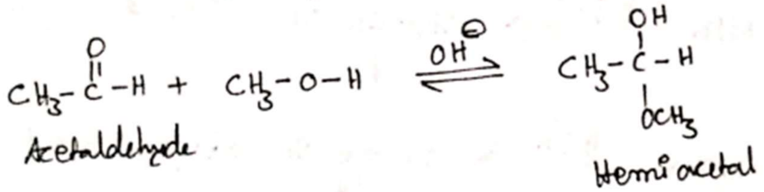
$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow{HSO_3Na} CH_3-\underset{SO_3Na}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-CH_3$$

c) Reaction with alcohols

Addition of alcohols is Catalysed by acid (or) base

Case-I Base catalysed addition

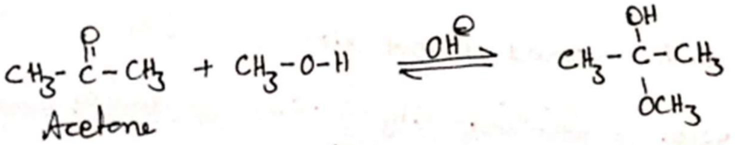
In presence of base 1eq of alcohol reacts with 1eq of Carbonyl comp to form hemi acetal (aldehyde as reactant) (or) hemi ketal (ketone as reactant)



$$CH_3-\overset{O}{\overset{\|}{C}}-H + CH_3-O-H \underset{}{\overset{OH^{\ominus}}{\rightleftharpoons}} CH_3-\underset{OCH_3}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-H$$

Acetaldehyde

Hemi acetal



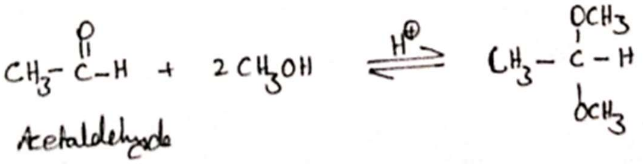
$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + CH_3-O-H \overset{OH^{\ominus}}{\rightleftharpoons} CH_3-\underset{OCH_3}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-CH_3$$

Hemi ketal

Acetone

Case-II Acid Catalysed addition

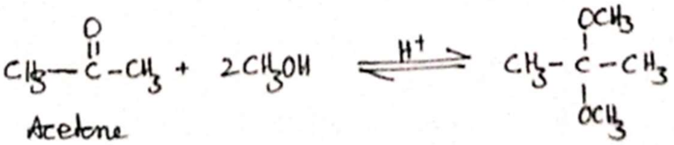
In presence of acid 1eq of Carbonyl Compound reacts with 2eq of alcohols to form acetal (aldehyde as reactant) (or) ketal (ketone as reactant)



$$CH_3-\overset{O}{\overset{\|}{C}}-H + 2CH_3OH \overset{H^{\oplus}}{\rightleftharpoons} CH_3-\underset{OCH_3}{\underset{|}{\overset{OCH_3}{\overset{|}{C}}}}-H$$

Acetal

Acetaldehyde



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + 2CH_3OH \overset{H^{+}}{\rightleftharpoons} CH_3-\underset{OCH_3}{\underset{|}{\overset{OCH_3}{\overset{|}{C}}}}-CH_3$$

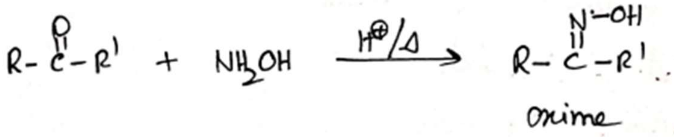
Ketal

Acetone

B. Nucleophilic addition followed by elimination reactions

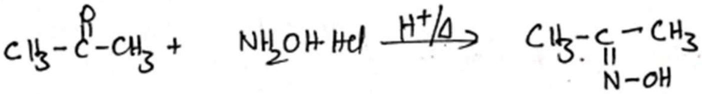
a) Reactions with hydroxylamine

Carbonyl Compounds react with Hydroxylamine to form oximes



$$R-\overset{O}{\overset{\|}{C}}-R' + NH_2OH \xrightarrow{H^{\oplus}/\Delta} R-\overset{N-OH}{\overset{\|}{C}}-R'$$

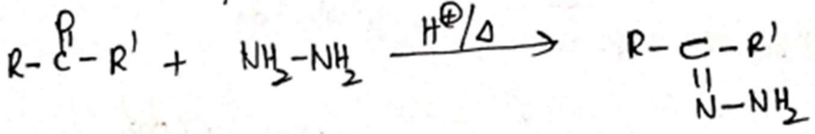
Oxime



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + NH_2OH\cdot HCl \xrightarrow{H^{+}/\Delta} CH_3-\underset{N-OH}{\underset{\|}{C}}-CH_3$$

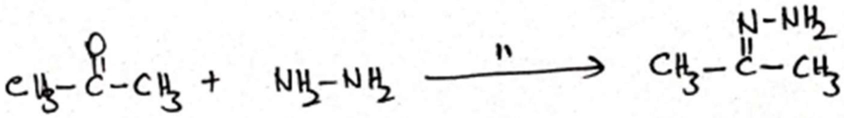
b) Reactions with hydrazine

Carbonyl compounds reacts with Hydrazine to form Hydrazone



$$R-\overset{O}{\overset{\|}{C}}-R' + NH_2-NH_2 \xrightarrow{H^{\oplus}/\Delta} R-\underset{\underset{N-NH_2}{\|}}{C}-R'$$

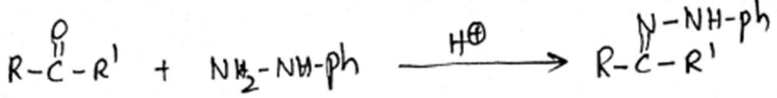
(Hydrazone)



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + NH_2-NH_2 \xrightarrow{''} CH_3-\overset{N-NH_2}{\overset{\|}{C}}-CH_3$$

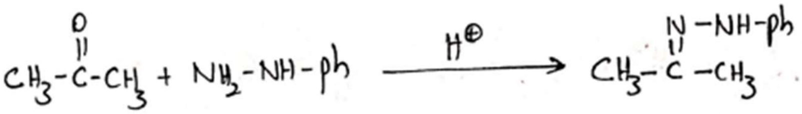
c) Reactions with phenyl hydrazine

Carbonyl compounds reacts with phenyl hydrazine to form phenyl hydra



$$R-\overset{O}{\overset{\|}{C}}-R' + NH_2-NH-ph \xrightarrow{H^{\oplus}} R-\overset{N-NH-ph}{\overset{\|}{C}}-R'$$

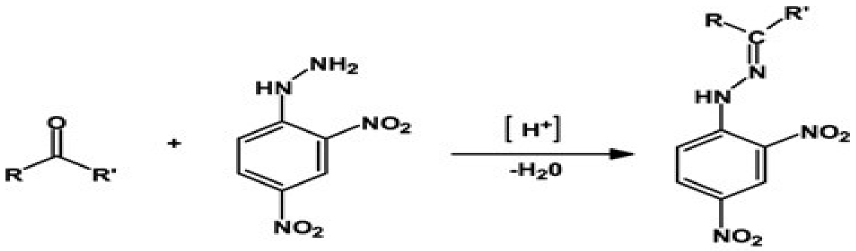
phenyl hydrazone



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + NH_2-NH-ph \xrightarrow{H^{\oplus}} CH_3-\overset{N-NH-ph}{\overset{\|}{C}}-CH_3$$

d) Reactions with 2,4 DNP

Carbonyl compounds are simply mixed with an acid solution of 2,4 DNP in methanol. yields 2,4-dinitrophenylhydrazones.

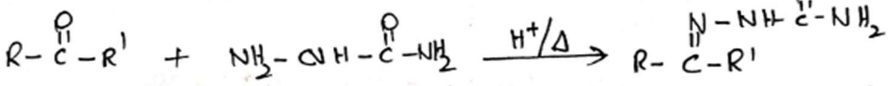


2,4-Dinitrophenylhydrazine (DNPH)

DNPH Derivative (a hydrazone)

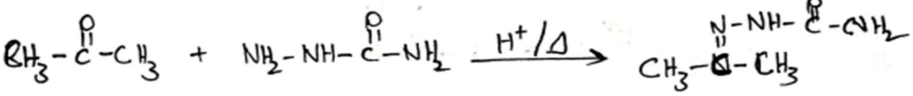
e) Reactions with semicarbazide

Carbonyl compounds reacts with Semicarbazide to form Semicarbazone



$$R-\overset{O}{\overset{\|}{C}}-R' + NH_2-NH-\overset{O}{\overset{\|}{C}}-NH_2 \xrightarrow{H^+/\Delta} R-\overset{N-NH-\overset{O}{\overset{\|}{C}}-NH_2}{\overset{\|}{C}}-R'$$

semi Carbazone



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + NH_2-NH-\overset{O}{\overset{\|}{C}}-NH_2 \xrightarrow{H^+/\Delta} CH_3-\overset{N-NH-\overset{O}{\overset{\|}{C}}-NH_2}{\overset{\|}{C}}-CH_3$$

C) Oxidations reactions

Carbonyl compounds under go oxidation with various oxidising reagents

with Benedict's solution: ($CuSO_4 + Na_2CO_3$ + sod. Citrate)

It oxidises aliphatic aldehydes only

$$CH_3-CHO + Cu^{+2} \longrightarrow CH_3COOH + Cu^{+} (Cu_2O) \text{ Red ppt}$$

with Tollen's Reagent (Ammonical Silver nitrate)

It oxidises aliphatic and aromatic aldehydes

$$R-CHO + Ag^{+} \longrightarrow RCOOH + Ag$$

$$Ph-CHO + Ag^{+} \longrightarrow PhCOOH + Ag$$

oxidising agents : $KMnO_4/OH^{\ominus}/\Delta$; $KMnO_4/H^{+}/\Delta$; $K_2Cr_2O_7/H^{\oplus}/\Delta$

Aldehydes are oxidised into Corresponding acids

$$RCHO \xrightarrow{(O)} RCOOH$$

$$C_6H_5CHO \xrightarrow{KMnO_4/OH^{\ominus}/\Delta} C_6H_5COOH$$

Ketones undergo oxidation only in drastic conditions.

oxidation at α-CH_2 (or) CH_3 by SeO_2

$$CH_3-CHO \xrightarrow{SeO_2} \underset{\text{Glyoxal}}{CHO-CHO}$$

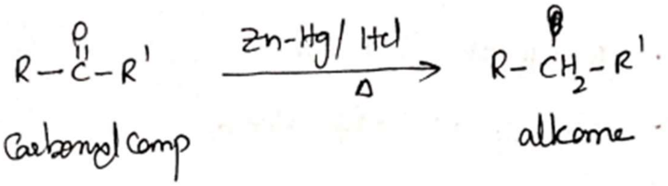
$$CH_3-CH_2-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow{SeO_2} CH_3-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-CH_3$$

$-CH_2-$ is more reactive than $-CH_3$

D) Reduction reactions

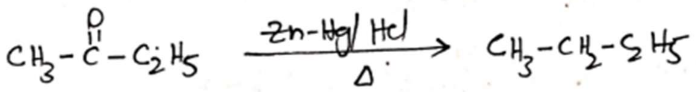
a) Clemmensen's reduction

Reduction of aldehydes or ketones to alkanes using zinc amalgam and Conc HCl.



$$R-\overset{O}{\overset{\|}{C}}-R' \xrightarrow[\Delta]{Zn-Hg/HCl} R-CH_2-R'$$

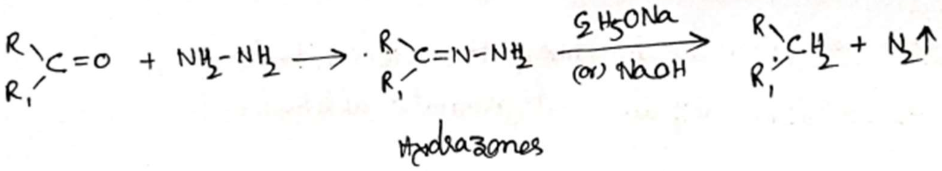
Carbonyl comp   alkane



$$CH_3-\overset{O}{\overset{\|}{C}}-C_2H_5 \xrightarrow[\Delta]{Zn-Hg/HCl} CH_3-CH_2-C_2H_5$$

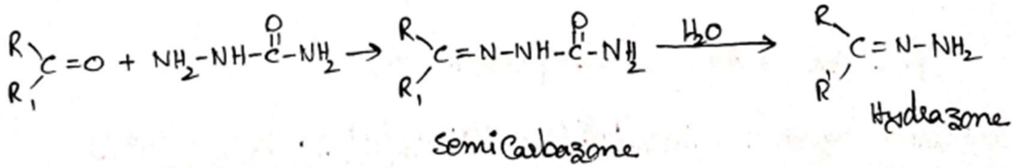
b) Wolf–Kishner's reduction

Reduction of hydrazones, semicarbazones (or) azines of aldehydes (or) ketones to hydrocarbons in basic condition is known as Wolf-Kishner reduction.



$$R(R_1)C=O + NH_2-NH_2 \longrightarrow R(R_1)C=N-NH_2 \xrightarrow[(or)\ NaOH]{C_2H_5ONa} R(R_1)CH_2 + N_2\uparrow$$

Hydrazones



$$R(R_1)C=O + NH_2-NH-\overset{O}{\overset{\|}{C}}-NH_2 \longrightarrow R(R_1)C=N-NH-\overset{O}{\overset{\|}{C}}-NH_2 \xrightarrow{H_2O} R(R')C=N-NH_2$$

Semicarbazone   Hydrazone

In reduction of semicarbazones & azines, the derivatives were first converted to hydrazone then to corresponding alkanes.

c) Reduction with LiAlH4

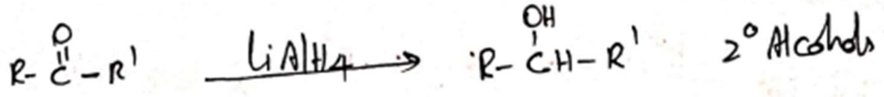
Carbonyl compounds reduced with $LiAlH_4$ to form alcohols

Aldehydes $\xrightarrow{LiAlH_4}$ 1° Alcohols

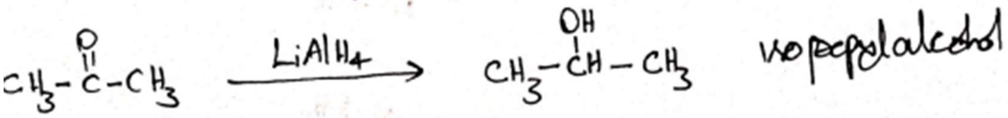
Ketones $\xrightarrow{LiAlH_4}$ 2° Alcohols

$$R-CHO \xrightarrow{LiAlH_4} R-CH_2OH$$ 1° Alcohols

$$CH_3-CHO \xrightarrow{LiAlH_4} CH_3-CH_2-OH$$ Ethyl alcohol



$R-\overset{O}{\overset{\|}{C}}-R' \xrightarrow{LiAlH_4} R-\overset{OH}{\overset{|}{C}}H-R'$ 2° Alcohols



$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow{LiAlH_4} CH_3-\overset{OH}{\overset{|}{C}}H-CH_3$ isopropyl alcohol

d) Reduction with $NaBH_4$

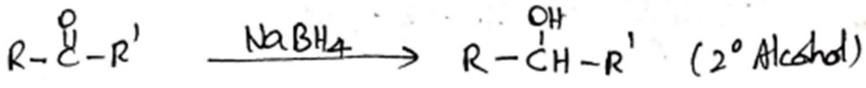
Carbonyl compounds reduced with $NaBH_4$ to form alcohols

i) Aldehydes $\xrightarrow{NaBH_4}$ 1° Alcohols

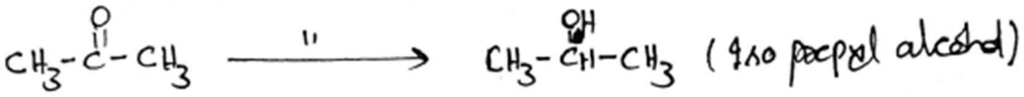
$R-CHO \xrightarrow{NaBH_4} R-CH_2-OH$ (1° Alcohol)

$CH_3-CHO \xrightarrow{NaBH_4} CH_3-CH_2-OH$ (Ethyl alcohol)

ii) Ketones $\xrightarrow{NaBH_4}$ 2° Alcohols



$R-\overset{O}{\overset{\|}{C}}-R' \xrightarrow{NaBH_4} R-\overset{OH}{\overset{|}{C}}H-R'$ (2° Alcohol)

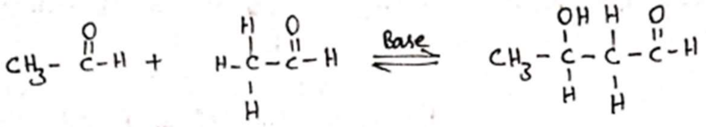


$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow{''} CH_3-\overset{OH}{\overset{|}{C}}H-CH_3$ (Iso propyl alcohol)

NAMED REACTIONS

a) Aldol Condensation

condensation of two molecules of an aldehyde (or ketones (with atleast one α- Hydrogen atom) to form β- hydroxy aldehyde or β-hydroxy ketone is known as aldol condensation.



$$CH_3-\overset{O}{\overset{\|}{C}}-H + H-\underset{H}{\overset{H}{\overset{|}{\underset{|}{C}}}}-\overset{O}{\overset{\|}{C}}-H \xrightleftharpoons{Base} CH_3-\underset{H}{\overset{OH}{\overset{|}{\underset{|}{C}}}}-\underset{H}{\overset{H}{\overset{|}{\underset{|}{C}}}}-\overset{O}{\overset{\|}{C}}-H$$

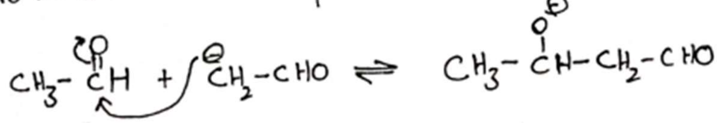
β-Hydroxy butyraldehyde

Mechanism

1. Formation of resonance stabilized Carbanion from aldehyde by the basic catalyst.

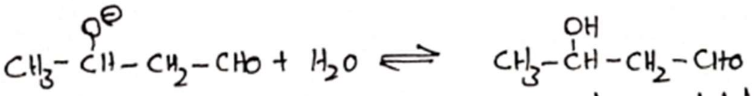
$$CH_3-CHO + \overset{\ominus}{OH} \rightleftharpoons [\overset{\ominus}{C}H_2-CHO \leftrightarrow CH_2=CH-\overset{\ominus}{O}]$$

2. The Carbanion attacks the Carbonyl Carbon of Second aldehyde molecule to form an addition product (alkoxide)



$$CH_3-\overset{O}{\overset{\|}{C}}H + \overset{\ominus}{C}H_2-CHO \rightleftharpoons CH_3-\overset{O^{\ominus}}{\overset{|}{C}}H-CH_2-CHO$$

3. Alkoxide abstracts H+ from water to form β-hydroxy aldehyde



$$CH_3-\overset{O^{\ominus}}{\overset{|}{C}}H-CH_2-CHO + H_2O \rightleftharpoons CH_3-\overset{OH}{\overset{|}{C}}H-CH_2-CHO$$

β-hydroxy aldehyde

b) Cannizzaro reaction

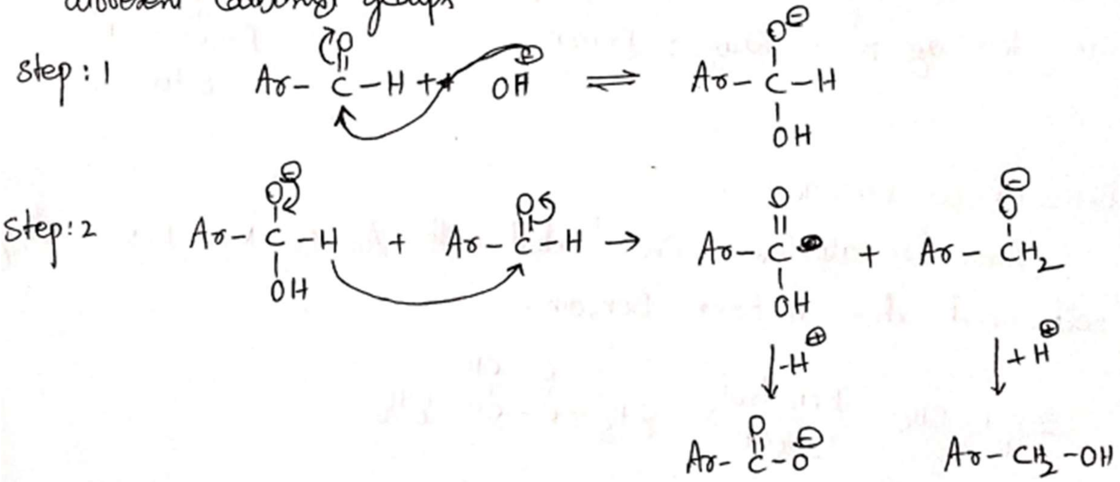
Aldehydes without α- Hydrogens, when treated with Conc alkali (Aq or Alc), undergo self oxidation-reduction to form a mixture of an alcohol and salt of Carboxylic acid.

$$2C_6H_5CHO \xrightarrow{Con\ Aq\ NaOH} C_6H_5CH_2OH + C_6H_5COOH$$

Benzaldehyde　　Benzyl alcohol　　Benzoic acid

Mechanism

The mechanism involves two successive nucleophilic addition, at different Carbonyl groups



c) Perkin reaction

Condensation of an aromatic aldehyde with an acid anhydride in presence of sodium salt of the same acid to form α,β unsaturated acid.

$$\underset{\text{Benzaldehyde}}{C_6H_5CHO} + \underset{\text{Acetic anhydride}}{(CH_3CO)_2O} \xrightarrow[\text{ii) } H^+]{\text{i) } CH_3COONa} \underset{\text{Cinnamic acid}}{C_6H_5CH=CHCOOH}$$

Mechanism

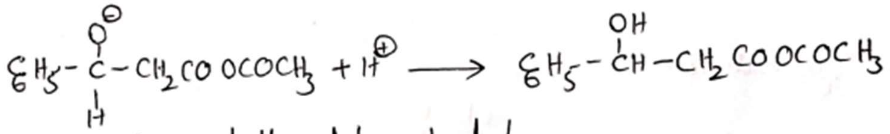
i) Acetate ion (from sodium acetate) abstracts hydrogen atom from the α- position of the anhydride to form Carbanion

$$CH_3-CO\cdot O\cdot COCH_3 + CH_3CO\overset{\ominus}{O} \longrightarrow \overset{\ominus}{C}H_2-COOCOCH_3 + CH_3COOH$$

ii) Carbanion attacks the Carbonyl Carbon of Benzaldehyde

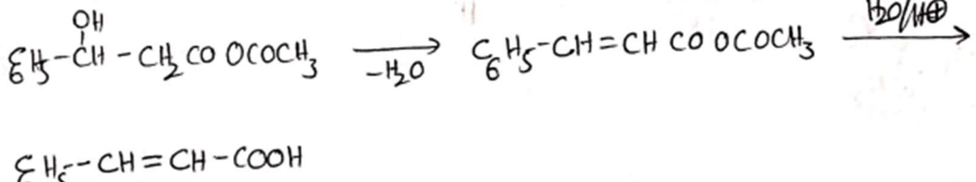
$$C_6H_5-\overset{O}{\underset{H}{\overset{\|}{C}}} + \overset{\ominus}{C}H_2COOCOCH_3 \longrightarrow C_6H_5-\overset{O^{\ominus}}{\underset{H}{C}}-CH_2COOCOCH_3$$

iii) Anionic oxygen of the carbonyl group is protonated, the required proton is furnished by CH_3COOH



$$C_6H_5-\overset{O^{\ominus}}{\underset{H}{C}}-CH_2COOCOCH_3 + H^{\oplus} \longrightarrow C_6H_5-\overset{OH}{C}H-CH_2COOCOCH_3$$

iv) Dehydration followed by hydrolysis.

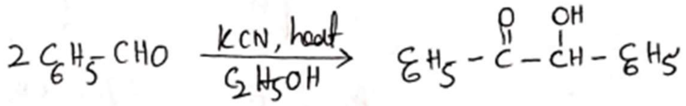


$$C_6H_5-\overset{OH}{C}H-CH_2COOCOCH_3 \xrightarrow[-H_2O]{} C_6H_5-CH=CHCOOCOCH_3 \xrightarrow{H_2O/H^{\oplus}} C_6H_5-CH=CH-COOH$$

Cinnamic acid.

d) Benzoin condensation

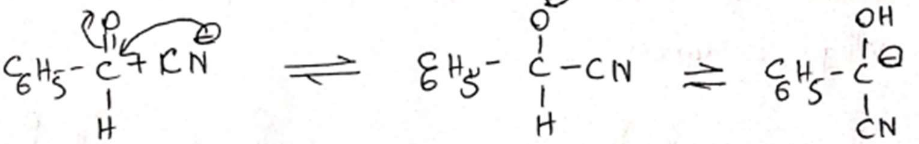
Aromatic aldehydes, when heated with Alc NaCN (or) KCN undergo self condensation to form Benzoin.



$$2\,C_6H_5CHO \xrightarrow[C_2H_5OH]{KCN,\ heat} C_6H_5-\overset{O}{\overset{\|}{C}}-\overset{OH}{C}H-C_6H_5$$

Mechanism

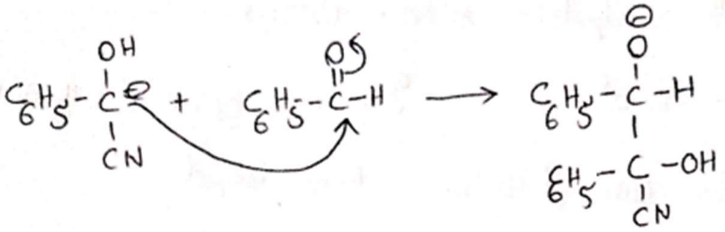
1. Nucleophilic addition of $CN^{\ominus}$ at the carbonyl carbon of benzaldehyde



$$C_6H_5-\underset{H}{\overset{O}{\overset{\|}{C}}} + CN^{\ominus} \rightleftharpoons C_6H_5-\underset{H}{\overset{O^{\ominus}}{C}}-CN \rightleftharpoons C_6H_5-\underset{CN}{\overset{OH}{C^{\ominus}}}$$

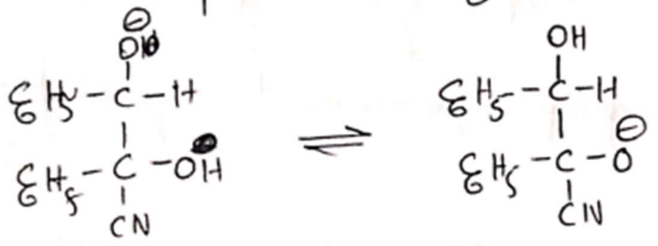
Resonance stabilized Carbanion

ii) attack of Resonance stabilized Carbanion on the carbonyl carbon of the 2nd molecule of benzaldehyde

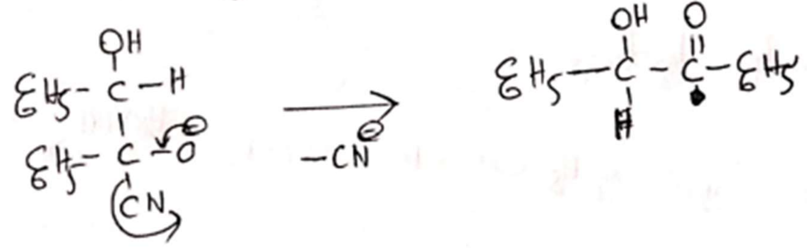


$$C_6H_5-\underset{CN}{\overset{OH}{C^{\ominus}}} + C_6H_5-\overset{O}{\overset{\|}{C}}-H \longrightarrow \begin{array}{c} C_6H_5-\overset{O^{\ominus}}{C}-H \\ | \\ C_6H_5-\underset{CN}{C}-OH \end{array}$$

iii) Transfer of proton to carbonyl carbon



iV Removal of cyanide ion



e) Claisen-Schmidt reaction

CLAISEN-SCHMIDT REACTION

Aromatic aldehydes which lack α-hydrogen condense with aliphatic aldehydes, ketones, esters having α-hydrogen in presence of 10% alkali solution to give α-β unsaturated aldehydes or ketones

$$\underset{\text{Benzaldehyde}}{C_6H_5CHO} + \underset{\text{Acetaldehyde}}{CH_3CHO} \xrightarrow{10\%\ NaOH} \underset{\text{Cinnamaldehyde}}{C_6H_5CH{=}CHCHO}$$

* Alkali be always in dilute state

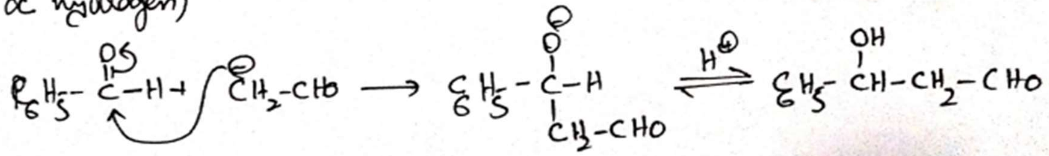
Mechanism

Mechanism:

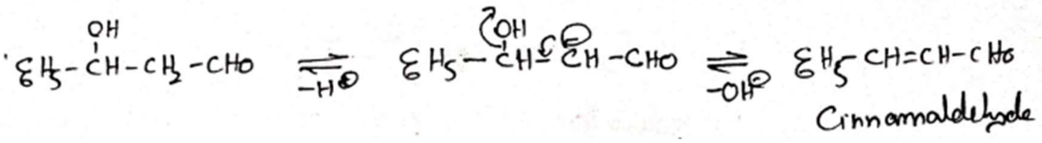
i) Base abstracts α-hydrogen from carbonyl compounds having α-hydrogen to form Carbanion

$$H-CH_2-CHO + \overset{\ominus}{OH} \longrightarrow \underset{\text{Carbanion}}{\overset{\ominus}{C}H_2CHO} + H_2O$$

ii) Carbanion attacks the carbonyl carbon of Aromatic aldehyde (with out α hydrogen)



iii)

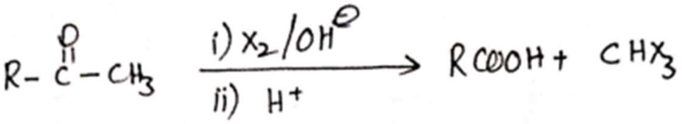


$C_6H_5-\overset{OH}{CH}-CH_2-CHO \underset{-H^{\oplus}}{\rightleftharpoons} C_6H_5-\overset{OH}{CH}-\overset{\ominus}{C}H-CHO \underset{-OH^{\ominus}}{\rightleftharpoons} C_6H_5-CH=CH-CHO$

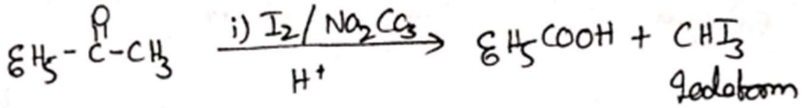
Cinnamaldehyde

f) Haloform reaction:

In this reaction α-methyl carbonyl compound undergo oxidation with $X_2/OH^{\ominus}$



$R-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow[ii)\ H^+]{i)\ X_2/OH^{\ominus}} RCOOH + CHX_3$



$C_6H_5-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow[H^+]{i)\ I_2/Na_2CO_3} C_6H_5COOH + CHI_3$

Iodoform

Mechanism